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Simulating Corn Yields for Two Iowa Soils

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ABSTRACT. *Corn yields in Iowa often could be improved with better water table management practices, but many soils in this region do not have adequate information about their yield potential. This study was conducted to evaluate the applicability of DRAINMOD in simulating crop yields for artificially drained soils of central and northeastern Iowa. Ten years of field data on crop yields from two drainage experimental sites in Iowa were used to compare relative crop yields with yields predicted by DRAINMOD. Data on saturated hydraulic conductivity, soil-moisture tensions, soil infiltration, and other physical properties were collected either at the experimental sites or in the laboratory on disturbed soil samples. Data on upward flux and infiltration constants for the Green and Ampt equation were calculated by using the infiltration data and soil-moisture retention characteristics of the surface layer. Relative crop yields predicted by DRAINMOD were reasonably close to the observed relative yields for both Iowa sites. Standard error of the estimates of relative yields was 17.41% and the average deviation was 12.99%. The coefficient of determination, r^2, between the predicted and measured yields was 0.54. Overall performance of the model suggests that DRAINMOD can be used successfully for predicting yields for different locations if data on site characteristics, soil-water properties, and plant growth functions are available.* **Keywords.** *Water table management, Artifically drained soils, Computer simulation, Corn Yields.*

Response of crops to excessive wet and dry conditions is not completely understood. The relationship between crop growth and soil moisture could be studied either by conducting long-term field experiments or by using well-tested computer simulation models. Often, it is either too wet or too dry for optimum crop growth. In some areas, even average seasonal weather could produce some kind of stress on plant growth. Crop stress could occur from a number of factors. A shortage of soil-water in midsummer is by far the most frequently occurring and detrimental factor of crop growth in Iowa. Inadequate moisture during any period of growth can result in reduced grain yield. Processes such as nutrient uptake and chemical transport in the soil-plant environment will not function successfully without sufficient water in the soil profile. Plants weakened by moisture stress are also more susceptible to diseases. Adverse soil moisture conditions in combination with other factors such as nutrient deficiencies, diseases, insects, and weeds interact to create many different kinds of crop stresses. If a field study is to be conducted to understand the effects of these stresses on crop growth, it will require many research projects funded over a longer period of time. Another option is to use well tested computer simulation models for such studies.

During the past decade, researchers have been developing computer models to simulate crop growth as a function of soil and climatic conditions. These simulation models have been used to analyze crop response to excessive and deficient soil-water conditions (Kanwar et al., 1983; Hardjoamidjojo and Skaggs, 1982; Ravelo et al., 1982; Shaw, 1974; Sudar et al., 1979). One of the most-used subsurface water management computer simulation models in the literature is DRAINMOD. Since 1973, this water management model has been under continuous development by Skaggs (1978) for soils with shallow water tables. In 1982, the Stress Day Index (SDI) concept was incorporated into DRAINMOD to quantify the effect of soil-water stresses on corn yields.

The SDI approach can be used to quantify the effects on crop yields caused by both excessive and deficient soil-water (Hiler and Clark, 1971). Models using the SDI concept to predict crop yields in relation to deficient soil-water conditions have been developed by Shaw (1978) and Sudar et al. (1979). A model based on the SDI concept was developed by Hardjoamidjojo and Skaggs (1982) to characterize the effects of excessive soil water on crop yields. The crop yield version of DRAINMOD has been used successfully to evaluate water management schemes for several different regions (Hardjoamidjojo and Skaggs, 1982; McMahon et al., 1988). DRAINMOD was also used successfully in Iowa in 1990 to predict subsurface drain flows and water table elevations for Nicollet silt loam and Kenyon soils, respectively (Sanoja et al., 1990). The major objective of this research was to evaluate the reliability of the yield version of DRAINMOD to successfully predict

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corn yields for these two artificially drained soils in Iowa (Nicollet silt loam and Kenyon loam).

MODEL DESCRIPTION

CROP RESPONSE VERSION OF DRAINMOD

The water management model, DRAINMOD (Skaggs, 1978), provides the basic framework to compute the water table position and the soil-water regime in the root zone of artificially drained and irrigated agricultural fields. DRAINMOD is based on a water balance concept at the midpoint between parallel drains for soils having an impermeable layer at a known depth from the soil surface. Detailed description of various model processes and input data needs for the nonyield version of DRAINMOD are given by Skaggs (1978). The water management version of DRAINMOD has already been evaluated for Iowa soils (Sanoja et al., 1990).

The yield version of DRAINMOD (Hardjoamidjojo and Skaggs, 1982) defined the relative yield as a function of three components:

$$\text{Yr} = \text{Yrw} \times \text{Yrd} \times \text{Yrp} \qquad (1)$$

where Yr is the relative yield (% of maximum potential yield),Yrw is the relative yield with excess soil-water conditions (%), Yrd is the relative yield resulting from the effect of drought stress on yield (%), Yrp is the relative yield that results when planting delays affect crop yield (%). Each relative yield is determined as a function of the potential yield, the yield expected in the absence of planting delays, and soil-water stresses.

Yrw is computed by using the SDI method, which considers the crop susceptibility to excessive soil-water conditions for different growth stages during the growing season.

The model used for predicting corn yield response can be summarized as:

$$\text{Yrw} = \text{Yrwmax for SDIw} \leq 8 \qquad (2)$$

$$\text{Yrw} = \text{Yrwmax}$$

$$- \text{Dslope} \times \text{SDIw for } 8 < \text{SDIw} < (\text{Yrwmax/Dslope}) \qquad (3)$$

$$\text{Yrw} = 0.00 \text{ for SDIw} > (\text{Yrwmax/Dslope}) \qquad (4)$$

where Yrwmax is the maximum yield (%) in the absence of excessive soil-water, Dslope is the slope of the predicting equation, and SDIw is the SDI for wet conditions. The SDIw is expressed as:

$$\text{SDIw} = \sum_{i=1}^{N} [\text{ CSwi} \times \text{SDwi }] \qquad (5)$$

where N is the number of days in the growing season, CSwi is the crop susceptibility factor for excessive wet conditions for day i (as affected by genotype, soil type, fertility, temperature, etc. and defined by Hiler and Clark, 1971), and SDwi is the stress day factor for day i and is taken as the daily value of SEW_{30} (Sum of Excess Water). The SEW_{30} was defined by Sieben (1964) and has been used by many researchers including Kanwar et al. (1988).

Shaw (1978) developed a corn-response model for deficient soil-water conditions. The crop response was incorporated in DRAINMOD by Hardjoamidjojo and Skaggs (1982) and may be written as:

$$\text{Yrd} = \text{Yrdmax} - \text{yrdslope} \times \text{SDId} \qquad (6)$$

where Yrdmax is the maximum relative yield (%) in the absence of deficient soil-water stresses, Yrdslope is the slope of the predicting equation, and SDId is the SDI for drought conditions. The SDI for drought conditions is expressed as:

$$\text{SDId} = \sum_{i=1}^{N} [\text{ SDdi} \times \text{CSdi }] \qquad (7)$$

where SDdi and CSdi are, respectively, the stress day and crop susceptibility factors for growth period i, and N is the number of periods in the growing season. The SDdi is defined as:

$$\text{SDdi} = \sum_{j=1}^{Ni} [\ 1 - \text{AETj / PETj }] \qquad (8)$$

where AET and PET are, respectively, the actual and potential daily evapotranspiration (ET), and Ni is the number of days in the *ith* growing period.

DRAINMOD also has the capability to predict the yield response caused by a delayed planting date. Corn yields are reduced if the planting date is delayed beyond an optimum period. DRAINMOD determines whether trafficable conditions exist each day and keeps a running total of suitable working days during the planting period. When enough working days have occurred to complete seedbed operations, the planting date is fixed (Hardjoamidjojo and Skaggs, 1982). The length of planting date beyond the optimum is determined, and the relative yield, Yrp, is estimated from the equation:

If PDELAY < DELAY1,

$$\text{Yrp} = 100 - \text{PDRF} \times \text{PDELAY} \qquad (9)$$

If PDELAY > DELAY1,

$$\text{Yrp} = 100 - \text{PDRF} \times \text{PDELAY} - \text{PDRF2} \times \text{PDELAY}$$

$$- \text{PDRF2} \times (\text{PDELAY} - \text{DELAY1}) \qquad (10)$$

where DELAY1 is a breakpoint past where the yields decrease at a faster rate, and PDRF and PDRF2 are the slopes before and after the breakpoint. Detailed descriptions of various model processes of the yield version of DRAINMOD and input data needs are given by Hardjoamidjojo and Skaggs (1982).

DESCRIPTION OF FIELD EXPERIMENTS

DRAINMOD was earlier tested and evaluated by using data on daily water table depths and subsurface drain flows from two drainage experiments in central and northeastern Iowa (Sanoja et al., 1990). Experimental data used in this research were collected from two long-term field experiments conducted at the Iowa State University

Agronomy and Agricultural Engineering Research Center near Ames in central Iowa and at the Iowa State University Northeastern Research Center near Nashua in northeastern Iowa.

The first set of data was obtained from a drainage experiment conducted at the central Iowa experimental site. The experimental site was on Nicollet silt-loam soil from the Clarion-Nicollet-Webster Soil Association. The Nicollet series consists of somewhat poorly to moderately well-drained soils with a slope of less than 2%. The drainage system at the experimental site consisted of 102 mm (4 in.) diameter clay tiles in parallel lines spaced 36.6 m (120 ft) apart. These subsurface tile lines were installed at a depth of 1.22 m (4.0 ft) in 1960. To provide access to the subsurface tile line, a sump 1.52 m (5.0 ft) deep was installed to intercept the drain tile. A float-activated recorder was installed in conjunction with an H-flume to provide a record of tile flow rates as a function of time. Daily tile flow rates were collected from 1984 through 1987 at this site. The data compared well with the predicted tile flows by DRAINMOD (Sanoja et al., 1990). Observation wells [1.8 m (6 ft) long and 38 mm (1.5 in.) diameter] were installed 30 m (100 ft) apart in the plot, midway between subsurface drains to measure water table depths. Observation wells were read three times a week during 1984 through 1987.

This site was planted to continuous corn during the period of this study. A single application of 175 kg/ha (156 lb/acre) of N-fertilizer was applied at the time of planting each year. The data on the average corn yields from this plot were used for testing and evaluating the yield version of DRAINMOD.

A second set of test data was obtained from a drainage experiment conducted at the Iowa State University Northeastern Research Center near Nashua in northeastern Iowa. The soils at the experimental site are predominantly Kenyon loam in the Kenyon-Clyde-Floyd Soil Association. Kenyon soils are gently sloping on ridge slope and moderately sloping on side slopes. These soils are moderately well drained, with a thick, dark, loamy surface layer and a high available water capacity (Kanwar et al., 1984). At the experimental site, plastic pipe drains were installed at a depth of 1.22 m (4.0 ft) with a trenchless plow and a trencher. All tile lines were spaced 24.6 m (80 ft) apart and arranged in groups of three lines installed with a trencher, alternated with three lines installed with a plow, to allow measurement relative to the middle line and to permit better isolation of the installation methods. The middle lines, once installed with each method, were monitored for water table depths during the crop growing season (April through November) for five years (1980 through 1984). Data on water table depths were collected from observation wells installed to a depth of 1.22 m (4.0 ft) midway between tile lines. Water table depths were read once a week from April through November for five years (1980 through 1984). The hydrology component of DRAINMOD was also evaluated for this site. The water table depths predicted by DRAINMOD agreed well with the observed data (Sanoja et al., 1990). Data on corn yields from this experimental site were used to test the reliability of the yield version of DRAINMOD. Table 1 shows the planting date, harvesting date, and average corn yields for five years at the experimental sites in central and northeastern Iowa.

Table 1. Average crop yields at the experimental sites in central and northeastern Iowa

Year	Planting Date	Harvesting Date	Corn Yields, kg/ha (lb/ac) Central Iowa	Corn Yields, kg/ha (lb/ac) Northeastern Iowa
1980	23 May	23 Oct		8442 (7538)
1981	18 May	3 Oct		8319 (7428)
1982	2 Jun	8 Nov		9176 (8193)
1983	26 May	19 Oct		4886 (5473)
1984	12 May	15 Oct		9563 (10711)*
1984	14 May	2 Oct	8300 (9296)	
1985	2 May	21 Oct	7400 (8288)	
1986	7 May	21 Oct	10700 (11984)†	
1987	1 May	6 Oct	7400 (8288)	
1988	5 May	6 Oct	4200 (4704)	

* Potential yield for northeastern Iowa site.
† Potential yield for central Iowa site.

Model Input Data

Various inputs to DRAINMOD include climatological, soil, drainage system, and crop parameters data.

Climatological Data

The precision of model prediction of infiltration, runoff, and subsurface drainage is influenced by the complete description of the rainfall intensity, duration, and time distribution. To get good estimates of model input parameters, hourly precipitation data were obtained from a rain gage station located about 200 m (660 ft) from the experimental site near Ames. Data on daily maximum and minimum temperatures used to estimate PET by the Thornthwaite method were also collected at this local station.

At the experimental site near Nashua, daily precipitation and temperature data were obtained from the nearby weather station at Charles City, Iowa. For model testing, daily precipitation was distributed uniformly over the entire day, and hourly precipitation was calculated to be used as input to the model.

Soil and Drainage Parameters Data

The soil parameters needed by DRAINMOD are the saturated hydraulic conductivity, the relationship between drainage volume and water table depth, the infiltration parameters for the Green-Ampt equation, the soil-water content at the wilting point, the depth of the impermeable layer, and the relationship between upward flux versus depth of the water table to supply ET requirements. Data on all these parameters were determined either in the field or laboratory and the values used for these parameters and relationships were the same as those described in detail by Sanoja et al. (1990).

Crop Input Data

The effective rooting depth zone for corn for two Iowa soils was taken from Shaw (1963). An effective rooting depth as a function of time is used in DRAINMOD to define the zone from which water can be removed to satisfy the ET demand. Table 2 gives the effective rooting depth as a function of time.

Table 2. Effective rooting depth as a function of time (Sanoja et al., 1990)

Month	Days	Root Depth cm (in.)
1	1	5 (2)
5	1	6 (2.4)
6	1	15 (6)
6	21	30 (12)
7	2	45 (18)
7	17	60 (24)
8	15	60 (24)
10	15	60 (24)
12	31	5 (2)

The model for predicting corn yield response to excessive soil-water conditions was developed from an analysis of the results of long-term field drainage experiments in Iowa (Kanwar et al., 1988). Kanwar et al. (1988) developed a model to quantify the effect of high water tables on corn yield of the form:

$$Yrw = 0.90 - 0.00036\ SDIw \text{ with } r^2 = 0.88 \quad (11)$$

where Yrw is the relative yield Y/Yo (%), Yo is the potential yield or the expected yield in the absence of soil-water stresses. Y is the yield when crop growth and production are limited by wet soil conditions, and SDIw is the stress caused by excessive wet conditions. Equation 11 shows that when the value for SDIw is zero, the relative yield (Yrw) would be 90%. But under practical situations the relative yield should be 100% at no excessive wetness stress (i.e., at SDIw = 0). One of the reasons that this model predicted only 90% relative yield at SDIw = 0 was because of the fact that Kanwar et al. (1988) had used the entire experimental data for developing this model. Some of the experimental plots gave relative yields less than one at SDIw values equal to zero due to some other factors such as weed infestation and lower plant population. Therefore, the model developed by Kanwar et al. (1988) (eq. 11) was modified by removing the data on relative yields less than one at zero SDIw to give a modified model as shown by equation 12 with an r^2 value of 0.85. This r^2 value is lower than the r^2 value for equation 11 because we forced the intercept of regression line of equation 12 to pass through 100.

$$Yrw = 100 - 0.17\ SDIw \text{ with } r^2 = 0.85 \quad (12)$$

Equation 12 was used in this article for yield analyses and is summarized by equations 13 through 15.

$$Yrw = 100 \text{ for } SDIw = 0 \quad (13)$$

$$Yrw = 100 - 0.17\ SDIw \text{ for } 0 < SDIw < 500 \quad (14)$$

$$Yrw = 0 \text{ for } SDIw > 500 \quad (15)$$

Normalized crop susceptibility factors (NCS) for corn were obtained from data collected by Evans et al. (1986). The reason for using NCS factors was to eliminate the effects of soil type, fertility, temperature and other factors affecting the yield response. Table 3 gives the normalized crop susceptibility factors for wet conditions as a function of time after planting.

Table 3. Normalized crop susceptibility factors for corn for excessive soil-water conditions (Kanwar et al., 1988; after Evans et al., 1986)

Growth Stage	Days after Planting	Normalized Mean Crop Susceptibility Factors
Establishment	18	0.16
Early Vegetative	36	0.18
Late Vegetative	56	0.38
Flowering	76	0.21
Yield Formation	100	0.06

Shaw (1978) developed a corn response model for deficient soil-water conditions based on extensive research in Iowa. This model was used in this study and may be written in the normalized form as:

$$Yrd = 100.0 \text{ for } SDId = 0.0 \quad (16)$$

$$Yrd = 100.0 - 1.22 \times SDId \text{ for } 0.0 < SDId < 82.0 \quad (17)$$

$$Yrd = 0.0 \text{ for } SDId > 82.0 \quad (18)$$

where Yrd is the relative yield Y/Yo, Yo is the potential yield, Y is the yield when the plant is affected by deficient soil water only. SDId is the SDI caused by deficient soil water.

Shaw's crop susceptibility factors for five-day growing periods relative to the silking stage were used to evaluate deficient soil-water conditions on corn yield (table 4). The silking stage lasts 20 days in the middle of the growing season. Whenever the stress day factor (SDd) was 4.5 or greater for two or more consecutive five-day periods, Shaw (1974) recommended that the SDd for those intervals be multiplied by an additional factor of 1.5.

Corn yields are significantly reduced if planting is delayed beyond an optimum period. The reduction in corn yields caused by late planting has been well established in Iowa by Benson and Thompson (1974). A five-year study in northeastern Iowa shows a sharp decline in corn yield when corn is planted on 20 May and 30 May as compared with planting on 2 May and 10 May. Eight years of data indicate no yield difference for planting dates from 16 April to 12 May. Long-term studies at several experimental farms in Iowa indicate that, on the average, yields start to decline when corn is planted after 10 May to 15 May. Therefore, an assumption was made that crop yields did not decrease if planting date was 15 May or earlier. Also, crop yields, due to planting delays were calculated using two step functions as given in table 5. The

Table 4. Crop susceptibility factors used to evaluate deficient soil-water conditions on corn yield* (Shaw, 1974)

Period	Weighing Factor		Period	Weighing Factor	
8	before silking	0.50	1	after silking	2.00
7	" "	0.50	2	" "	1.30
6	" "	1.00	3	" "	1.30
5	" "	1.00	4	" "	1.30
4	" "	1.00	5	" "	1.30
3	" "	1.00	6	" "	1.30
2	" "	1.75	7	" "	1.20
1	" "	2.00	8	" "	1.00
			9	" "	0.50

* Periods are five-day intervals relative to silking.

Table 5. Crop response to delayed planting date (Benson and Thompson, 1974)

Last day to plant without yield reduction.	15 May
Breakpoint past which the yield decreases at a faster rate.	20 May
Slope before breakpoint (used between 16 May and 19 May).	0.00178
Slope after breakpoint (used after 20 May).	0.00523

yield response input data for delayed planting are given in figure 1 and table 5.

Model Evaluation

DRAINMOD was evaluated on the basis of its ability to accurately predict the corn yields for the growing seasons of 1980 through 1988. Model simulations were conducted from 1 April to 31 October for 1980 through 1984 for the experimental site in northeastern Iowa and for 1984 through 1988 for the experimental site in central Iowa (1984 data were used for model evaluation). Measured and predicted water table depths and tile flow rates were compared to evaluate the reliability of DRAINMOD at these two sites in an earlier study (Sanoja et al., 1990) and are summarized in table 6.

The standard error (SE) and the average deviation (AD) between the observed and predicted corn yields were calculated by using the equations:

$$SE = \left[\sum_{i=1}^{n} \frac{(Xi,p - Xi,o)^2}{n} \right]^{1/2} \tag{19}$$

$$AD = \frac{\left[\sum_{i=1}^{n} ABS\,(Xi,p - Xi,o) \right]}{n} \tag{20}$$

where Xi,p is the predicted corn yield in year i, xi,o is the observed corn yield in year i, and n is the number of observations.

Observed corn yields from both experimental sites were converted to relative yields by dividing the measured yield by the potential yield. The highest observed yields were 10 700 kg/ha (9554 lb/acre) for 1986 at the central Iowa site and 9563 kg/ha (8538 lb/acre) for 1984 at the northeastern Iowa site. They were taken as the base maximum yields and were used to determine the measured relative yields for all other years.

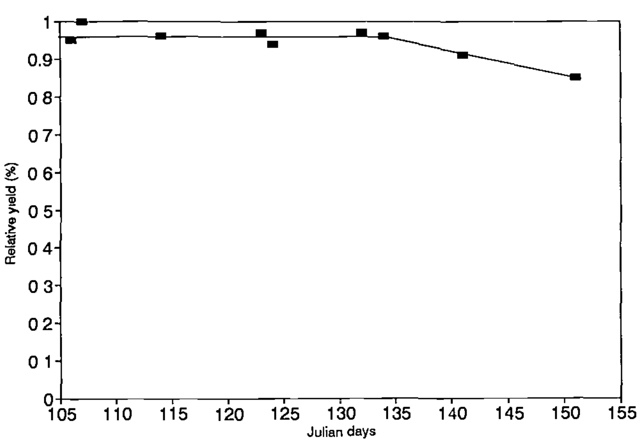

Figure 1–Relative yield as a function of the planting day (Benson and Thompson, 1984).

Table 6. Summary of the predicted and measured tile flow rates for Central Iowa Experimental site (Sanoja et al., 1990)

	1984		1986		1987	
Month	DRAINMOD Predicted cm (in)	Observed cm (in.)	DRAINMOD Predicted cm (in)	Observed cm (in)	DRAINMOD Predicted cm (in)	Observed cm (in.)
4	7 71 (3 1)	6 28 (2.5)	5 06 (2 0)	5.44 (2 2)	3 79 (1 5)	4 89 (1 9)
5	5 44 (2 2)	6 39 (2 6)	6 14 (2 5)	9 53 (3.8)	0 31 (0 12)	1 24 (0 5)
6	5 46 (2 2)	5 58 (2 2)	0 45 (0.2)	3 07 (1.2)	0 51 (0 2)	1 44 (0 6)
7	0.00 (0 0)	0 03 (0 01)	2 37 (0 95)	2 58 (1 03)	0 43 (0 17)	0 04 (0 02)
8	0 00 (0.0)	0 00 (0 0)	0 00 (0 0)	0 00 (0 0)	3.98 (1 6)	6 21 (2 5)
9	0 00 (0 0)	0 00 (0 0)	0 98 (0 4)	1 59 (0 64)	1.15 (0 46)	2 95 (1.2)
0	0 00 (0 0)	0 00 (0 0)	0 00 (0 0)	8 60 (3 4)	0 00 (0 0)	0 00 (0.0)
Total	18 61 (7 4)	18 28 (7 3)	22 22 (8 9)	30 81 (12 3)	10 17 (4 1)	16.77 (6 7)

Results and Discussion

Observed and predicted relative yields along with the components Yrw, Yrd, Yrp are given in table 7. In general, the relative yields predicted by the model were reasonably close to the observed relative yield values. When the comparisons were made for the overall averages of measured and predicted corn relative yields for 10 years, the agreement was acceptable. The average relative predicted and measured yields were 90% and 79%, respectively (table 7).

Figure 2 shows a relationship between the predicted and measured relative yields. The r^2-value between predicted and measured yield was 0.54 and means that 54% of the variations in measured yields are described by the model. The remaining 46% may be attributed to different factors, such as errors in input data, fertilizer input, weed population, solar radiation, temperature, etc.

At the experimental site in northeastern Iowa, the relative yields during the growing seasons of 1980 through 1983 were affected by planting delays (table 7). Long-term studies indicate that on the average, corn yields in Iowa start to decline when corn is planted after 15 May. Benson and Thompson (1974) found that with delayed planting, the length of time from tasseling to silking becomes longer. This delay in silking resulted in more sterile plants and higher grain moisture content at harvest. Benson and Thompson (1974) also noted that late silking is of greatest concern in years of short moisture supply, because the critical silking stage will more likely coincide with a period of greater moisture stress.

Table 7. Observed and predicted relative yields data at the experimental sites

Year	Yrw* %	Yrd† %	Yrp‡ %	Yr§ %	Yo ‖ %	Rain cm (in.)	ET cm (in.)
1980#	100 0	100 0	98 1	98 1	88 3	76 71 (30 7)	63 32 (25 3)
1981#	100.0	100 0	99.6	99 6	87 0	74 73 (29.9)	59 95 (24 0)
1982#	100 0	100 0	92 8	92 8	95.5	74 96 (30 0)	56 10 (22 4)
1983#	92 9	100 0	95 4	88 7	50 6	92 18 (36 9)	62 51 (25 0)
1984#	100 0	100 0	100 0	100 0	100 0	60.76 (24 3)	59 02 (23 6)
1984**	91 9	78 3	100 0	72 0	77 6	64 65 (25 9)	51 25 (20 5)
1985**	100 0	94 7	100 0	94 7	69 2	45 64 (18 3)	53 01 (21 2)
1986**	100 0	100 0	100 0	100 0	100 0	76 71 (30 7)	63 32 (25 3)
1987**	96 6	100 0	100 0	96 6	77 6	70 79 (28 3)	59 98 (24 0)
1988**	100 0	56 0	100 0	56 0	39 4	46 56 (18 6)	53 40 (21 4)
Average	98 1	92.9	98 6	89 9	78 5	68 37 (27 3)	58 20 (23 3)

* Relative yield to excess soil-water
† Relative yield to drought stress
‡ Relative yield to planting delays
§ Predicted relative yield
‖ Measured relative yield
\# Relative yield on northeastern Iowa site
** Relative yield on central Iowa site

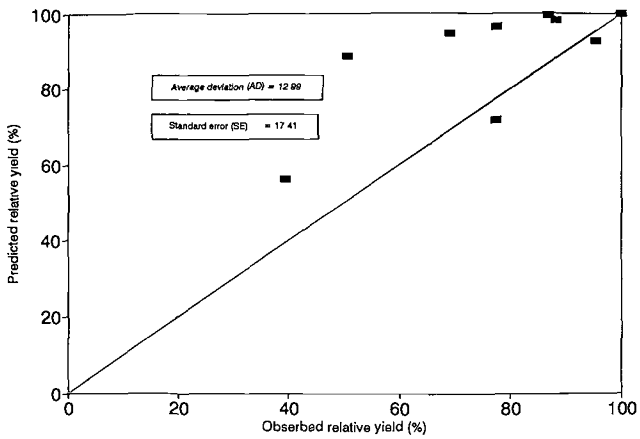

Figure 2–Relationship between the measured and predicted relative yield.

Stresses caused by deficient and excessive soil water conditions affected the yields in several years. Table 6 gives the monthly tile flow volumes (predicted and observed) for 1984, 1986, and 1987. This indicates that the model did a good job in simulating the hydrologic systems for central Iowa soils. Table 8 gives the SEW_{30} (an indicator of excessively wet days) and dry day values for various years at both locations.

The number of dry days (days during which ET is limited) can be a good indicator of the effects of drought stresses on crop yield. The model predicted the number of dry days to be 22, 34, and 41 for 1984, 1985, and 1988, respectively. Although 1985 and 1988 have similar rainfall during the growing season, the rainfall distribution in 1988 caused critical dry conditions for several months.

In 1985, corn yield was severely affected by moisture deficiency at the central Iowa location. There were 34 dry days in 1985 in the early part of the growing season (table 8). These dry conditions may have resulted in shallow root development, and nutrient stresses in the months of June and July. Nutrient stress is expected to happen during a drought because the upper part of the soil profile, where the fertilizer has been placed, is dry and out of the active root extraction zone. The yield response in DRAINMOD to soil-water deficiency does not take into account the reduction in yield caused by a shortage in soil-water from planting to emergence. As a consequence, the relative yield predicted by DRAINMOD will be higher, as was the case for the 1985 growing season (table 7).

Table 8. Predicted data on SEW_{30} and number of dry days for central and northeastern Iowa

	Northeastern Iowa			Central Iowa		
Year	Rain cm (in)	Dry Days days	SEW_{30} cm (in)	Rain cm (in)	Dry Days days	SEW_{30} cm (in)
1980	76 7 (30 7)	0	0 0 (0 0)			
1981	74 7 (29 9)	0	0 0 (0 0)			
1982	75 0 (30 0)	0	4 5 (1 8)			
1983	91 1 (36 4)	0	142 0(56 8)			
1984	60 8 (24 3)	0	0 0 (0 0)			
1984				69 7 (27 8)	22	204 9 (82 0)
1985				45 6 (18 2)	34	0 0 (0 0)
1986				83 4 (33 4)	0	109 6 (43 8)
1987				69 3 (27 7)	14	86 6 (34.6)
1988				46 6 (18 6)	41	0 (0 0)

DRAINMOD predictions for 1988 for the central Iowa location show the drastic effect of soil-water deficiency on corn yield. For the years 1984 through 1988, 1988 had the greatest number of dry days (table 8). Corn was under stress during the period of tasseling, silking, and pollination, which are considered the most critical stages in corn development. Such stresses extend the silking period and increase the time required for pollination. The result is that, sometimes, all the pollen may be shed before the silk emerges. Also, DRAINMOD predictions for 1984 for the central Iowa location and for 1983 for the northeastern location show the effect of excessive wetness (SEW_{30}) on corn yield where the predicted relative yields of 91.9% and 92.9% were obtained, respectively.

Mukhtar et al. (1990) found that corn yields were affected most when excess soil-water was present in the early growing stages of the crop. Excess moisture in the early vegetative stages may retard root development and create aeration-nutrition problems, making the plants more susceptible to drought stresses at later stages. The yields predicted by the model for the simulated period were in close agreement to the observed ones. Although final corn yields could be affected by several factors, the predictions were close to the observed values. Predicting crop yields is a complex system, but the results of this study indicate very strongly that DRAINMOD has the capability of simulating corn yields for the two locations in Iowa.

Summary and Conclusions

The yield version of DRAINMOD was evaluated by comparing the predicted and measured relative yields for central and northeastern Iowa sites. Predicted corn yields were in close agreement with the measured yield values although for some years significant differences were observed.

The overall agreement between the observed and predicted relative yields was good, with a standard error of 17.41% and an average deviation of 12.99%. The r^2-value between the predicted and measured yields was 0.54 for the 10-year period. These results, along with those of Sanoja et al. (1990), suggest that DRAINMOD can be used with a degree of reliability for predicting corn yields of a given area if data on hydrologic and plant growth parameters are available.

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